

Climate impact on the prime mover size and design of a CCHP system for the residential building

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ABSTRACT

Iran is a country with five different climates and 50 °C temperature difference between its warmest and coldest regions. In the present paper, the prime-mover capacity of a CCHP system for the same building in five different climates is determined. For this purpose, five cities from these climates are chosen and their weather information for the last five years is gathered from the Iran Metrological Organization. The hourly load of the five cities for the whole year is calculated and the maximum rectangle method is used to determine the size of the prime mover and the recommended full load operation time. The results show that the CCHP system saves energy during the whole year for all the climates. The yearly average fuel energy saving ratio of 37.85%, 33.16%, 30.75%, 29.60% and 25.30% are achieved for Chabahar, Ahwaz, Kamyaran, Tehran and Bandar Anzali, respectively. Furthermore, the analyses show that no heating system is needed for the cities of Chabahar and Ahwaz, but an auxiliary boiler is needed for all the climates to compensate the lack of heating or to support the absorption chiller. The sensitivity analysis shows that the hourly load of building is least sensitive to the minimum wet bulb temperature.

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1. Introduction

A CCHP system produces power and uses the waste heat for cooling and heating purposes. In comparison with the separate production of cooling, heating and power, the CCHP systems save energy and reduce environmental pollution. They also have higher safety in crises such as war or earthquake, and flexibility to be on-grid or off-grid [1–5].

Main subsystems of a CCHP system comprise of the prime mover, the heat exchangers and heat storage system for the heating purpose, thermally activated cooling system, control system and the energy resource used. The prime mover can be a gas turbine, reciprocating internal combustion engine, Stirling engine, steam turbine, micro gas or steam turbine and fuel cells. The thermally activated cooling system may include technologies such as absorption chiller, adsorption chillers, ejector refrigeration system and desiccant dehumidifiers [1].

Sizing prime mover for the CCHP systems is of great importance, because it affects the overall efficiency, primary energy saving, investment cost and environmental pollution. It also has impact on the optimum strategy selection for providing the required loads of

the building. Ref. [6] has done a thermo-economic analysis to specify the type and number of required micro-gas turbines to provide the electrical and thermal needs (CHP) of a commercial building in Tehran urban area during a year. They have done the sizing by maximizing an objective function called *annual profit*. Another study [7], determines the size and number of micro-gas turbine to follow the thermal load of a residential building in Tehran, Ahwaz and Hamedan. This research does not use any optimization technique and find the number and size of micro-gas turbine according to a simple and linear balance equation between the peak load of building and the heat or refrigeration produced by the heat exchangers or chillers respectively.

The effect of climate on sizing and designing of CCHP is not reported yet but [8] presents the impact of altitude on the performance of the CCHP system and its components. Among the researchers [9], used the MRM to size the prime mover by considering a constraint on the primary energy saving (PES) as the main criteria and using following thermal load strategy. In the MRM, the hourly thermal load of winter is determined and the area of a rectangle under the hourly thermal load curve must become the maximum, the width of the rectangle represents the prime mover size, and the length is the full load operation time of the prime mover. In a THT climate like the city of Chabahar in Iran, no heating is required during the whole year, and about 80% time of year the cooling system must be working, therefore the traditional MRM introduced by [9] cannot be used to size the prime mover. The Ref. [9] uses the hourly cooling load for sizing the absorption chiller.

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Nomenclature:

CCHP	combined cooling heating and power
CHP	combined heat and power
CL	cooling load of the building (kW)
COP _{ac}	coefficient of performance of the absorption chiller
FESR	fuel energy saving ratio (%)
HL	heating load of the building (kW)
MRM	maximum rectangle method
Q	heat (kW)
RH	relative humidity (%)
TDB	dry bulb temperature (°C)
TDC	tropical and dry in summer, cold in winter
TDEC	temperate and dry in summer, extremely cold in winter
THC	temperate and humid in summer, cold in winter
THT	tropical and humid in summer, temperate in winter
TSHT	tropical and semi-humid in summer, temperate in winter
TWB	wet bulb temperature (°C)

Finally, this paper uses the aggregated thermal demand to size the prime mover of a CCHP plant. Later in 2010, Ref. [10] developed the traditional MRM to three methods of vertical design, horizontal design and high-level analysis for sizing the prime mover. In the vertical design, the prime mover size becomes larger than that recommended by the traditional MRM until the PES reaches a predefined minimum value. On the contrary, in the horizontal design, the prime mover size recommended by the traditional MRM remains unchanged but the time when the prime mover operates in full load expands. This time expansion continues until a minimum PES is achieved. This helps to save energy all the time when the prime mover is working at full load. In the high-level analysis, in addition to the PES constraint, an economical evaluation is also considered. In this method at the beginning all the cases with the same minimum PES is found (an *iso*-PES curve is drawn) and then among these cases the economical criteria such as the net present value (NPV) and estimated economic returns (EER) is compared.

In the present paper, a hypothetical building is considered for all the climates of TDC, THC, TSHT, THT and TDEC. For each climate, a city is considered as the representative. The effect of climate on the hourly load profile, prime mover size, the heating and cooling systems and the FESR is investigated. For this purpose, the weather information of the last 5 years for the five cities is gathered from the Iran Metrological Organization and used to determine the yearly cooling and heating demand of the building. Then the traditional MRM is used to size the prime mover. Due to the low efficient power plants and high-loss electricity grid in Iran, the prime mover that is a reciprocating internal combustion natural gas fueled engine, operates at full load during the whole year and saves energy all the time. As the cooling or heating load of the building increases the FESR increases as well, and reaches its maximum as the heating or cooling load of the building approaches the total recovered heat from the prime mover. Furthermore, a sensitivity analysis is done to investigate the sensitivity of the hourly load profile to small changes in the designing parameters.

2. Climate classification

To classify the climate of regions in summer and winter, the following procedures are used.

In the summer, the tropical and temperate climates have TDB >40 °C and TDB <40 °C respectively. Moreover, the dry, semi-humid

Table 1

Overall classification of climate.

Climates	Summer	Winter	Example
TDC	Tropical and dry	Cold	Tehran
TSHT	Tropical and semi-humid	Temperate	Ahwaz
THT	Tropical and humid	Tropical	Chabahar
TDEC	Temperate and dry	Extremely cold	Kamyaran
THC	Temperate and humid	Cold	Bandar Anzali

and humid climates have $TWB < 23^{\circ}\text{C}$, $23^{\circ}\text{C} \leq TWB < 28^{\circ}\text{C}$ and $TWB \geq 28^{\circ}\text{C}$ respectively.

In the winter, the extremely cold, cold, temperate and tropical climates have the minimum TDB (°C) of −16, −9, −1 and 5.5 respectively. Finally, the overall summer–winter classification of climates with an example for each climate is presented in Table 1, [11].

3. The case study

In the present paper, a four-floor eight-unit hypothetical residential building with total living area of 1200 m² is considered. The specifications of the building are as follow:

The average ceiling height and building weight are 2.7 m and 468.7 kg/m² respectively. The walls are medium weight with the overall U-value of 1.53 W/(m² K). The overall U-values of floors above the unconditioned and conditioned spaces are 0.568 W/(m² K) and 2.839 W/(m² K) respectively. Each floor has fourteen double glazed windows, 6 mm argon gap type and each one has 2 × 2 (m) area. Total occupants are 32 people. The lighting is free hanging fixture type with the wattage of 43 W/m² and the ballast multiplier of 1.25.

The aforementioned building is considered in five different cities. Each city is a representative of a specific climate (Table 1). The cities are Ahwaz (TSHT), Tehran (TDC), Bandar Anzali (THC), Chabahar (THT) and Kamyaran (TDEC). The daily weather information including the maximum and minimum TDB and RH of the last five years (before that was not archived) is gathered from the Iran Metrological Organization for each city and used for calculation of the cooling and heating loads of the building.

The main electricity consumers and the corresponding power consumptions are as follow. The lighting index is 43 W/m², a TV-LCD (158 W), a washing machine (345 W), a refrigerator (140 W), a computer (225 W), and an iron (940 W). Considering a demand factor of 0.76, the electricity needed at pick hours becomes 42.4 kW.

The CCHP system that is supposed to provide cooling, heating and power of this building, uses an internal combustion engine to provide power, the recovered heat is used for heating or used in a single effect absorption chiller with COP_{ac} = 0.7 to provide cooling.

4. Analysis methodology

4.1. Weather and load calculations

To start the analyses, the daily weather information from the beginning of August 2006 to the end of July 2011 of the five cities is gathered from the available archive in the Iran Metrological Organization web site [12]. The information includes the daily maximum and minimum of TDB and RH. The monthly average of the TDB and RH for the 5 years calculated, and finally the average minimum and maximum TDB and RH of each specific month during the five years determined. The five-year averages of TDB and RH at the atmospheric pressure are used in the engineering equation solver (EES) to determine the corresponding TWB.

The weather information and the building data from the previous sections are used in the hourly analysis program (HAP) to

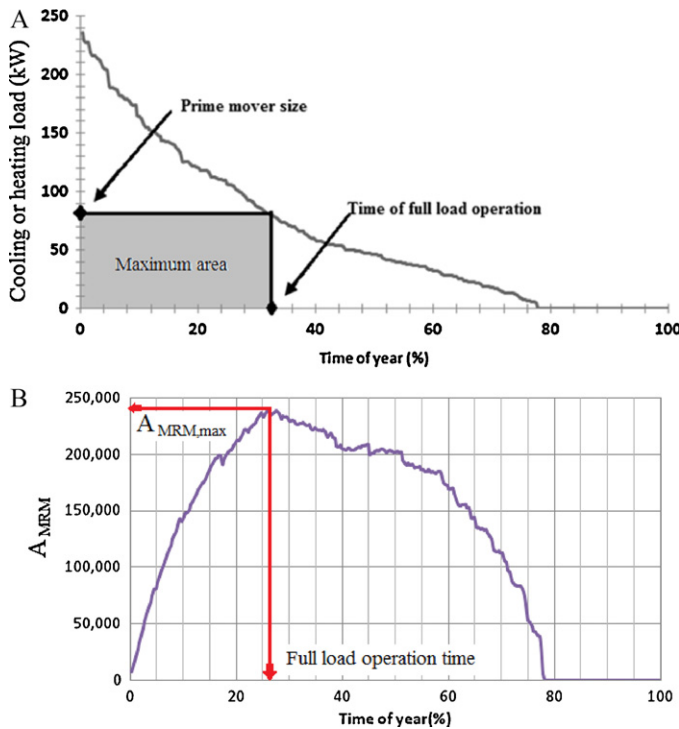


Fig. 1. Presentation of the traditional MRM.

calculate the cooling and heating loads during 24 h for each month in the five climates.

4.2. The sizing method

The aggregated thermal load that was calculated in the previous section is sorted from the maximum to minimum for the five cities and plotted against the time of year in percent. The MRM is used to size the prime mover. This technique uses the hourly load curve and finds the rectangle area under the hourly load curve as depicted in Fig. 1A. In the traditional MRM, the length and width of the rectangle represent the recommended full time operation during a year and size of the prime mover respectively. To determine the area under the rectangle (A_{MRM}) the length and width of rectangle are multiplied as below:

$$A_{MRM} \text{ (kWh)} = \text{Aggregated Thermal Load (kW)} \times \text{Time of year (\%)} \times 8760 \text{ (h)} \quad (1)$$

After calculation of the A_{MRM} it can be plotted versus the time of year (%) as illustrated in Fig. 1B. The maximum of A_{MRM} and the corresponding full load operation time can be found according to the A_{MRM} curve and as a result, the prime mover size (E_{PM}) is calculated as below:

$$E_{PM} = \frac{A_{MRM, \max}}{(\text{Full load operation time (\%)} \times 8760)} \quad (2)$$

4.3. Evaluation parameter

In order to evaluate the effectiveness of the CCHP system in saving energy for different climates the fuel energy saving ratio (FESR) and the overall efficiency (η_{overall}) are defined as below:

$$\text{FESR} = \frac{(\text{Fuel}_{sp} - \text{Fuel}_{CCHP})}{\text{Fuel}_{sp}} \quad (3)$$

$$\eta_{\text{overall}} = \frac{E_{PM} + x + Q_{\text{aux}, b}}{\text{Fuel}_{CCHP} + \text{Fuel}_{\text{aux}, b}}$$

$$x = \begin{cases} \text{COP}_{ac} \cdot Q_{rec} & \text{if cooling needed} \\ Q_{rec} & \text{if heating needed} \end{cases} \quad (4)$$

In which, the subscripts of sp, rec, ac, aux and b stand for the separate production, recoverable, absorption chiller, auxiliary and boiler respectively. According to the climates, the CCHP system has three different working modes; it may be used for producing cooling and power, heating and power or only power during the year.

a. Cooling and power mode:

In this mode, two states may happen; in the first case, the cooling load achieved from the recovered heat from the engine (Q_{rec}) meets the required cooling load of the building, hence:

$$\text{if } \text{COP}_{ac} \cdot Q_{rec} \geq CL :$$

$$\text{Fuel}_{sp} = \frac{E_{PM}}{\eta_{PP} \eta_G} + \frac{CL}{\text{COP}_{ac} \cdot \eta_b} \quad (5)$$

$$\text{Fuel}_{CCHP} = f(E_{PM})$$

In which, $f(E_{PM})$ represents the fuel consumed by the prime mover and can be derived from curve fitting of the data presented in the catalogue of the prime mover manufacturer. In the analyses it is assumed that, $\eta_{PP} \eta_G = 25.5\%$, $\text{COP}_{ac} = 0.7$, $\eta_b = 0.8$, in which η is the efficiency and subscripts of PP and G stand for the power plant and grid respectively.

In the second case the cooling load achieved from the recovered heat from the engine does not meet the required cooling load of the building, therefore an auxiliary boiler is necessary to compensate the lack of heat for the absorption chiller, hence:

$$\text{if } \text{COP}_{ac} \cdot Q_{rec} < CL :$$

$$\text{Fuel}_{sp} = \frac{E_{PM}}{\eta_{PP} \eta_G} + \frac{CL}{\text{COP}_{ac} \cdot \eta_b} \quad (6)$$

$$\text{Fuel}_{CCHP} = f(E_{PM}) + \text{Fuel}_{\text{aux}, b}$$

$$\text{Fuel}_{\text{aux}, b} = \frac{CL - \text{COP}_{ac} \cdot Q_{rec}}{\text{COP}_{ac} \cdot \eta_b} \quad (7)$$

b. Heating and power mode:

In this mode, as well, two states may happen; in the first case, the recovered heat from the engine meets the required heating load of the building, hence:

$$\text{if } Q_{rec} \geq HL :$$

$$\text{Fuel}_{sp} = \frac{E_{PM}}{\eta_{PP} \eta_G} + \frac{HL}{\eta_b} \quad (8)$$

$$\text{Fuel}_{CCHP} = f(E_{PM})$$

In the second case, the recovered heat from the engine does not meet the required cooling load of the building; therefore, an auxiliary boiler is necessary to compensate the lack of heat for the heating, hence:

$$\text{if } Q_{rec} < HL :$$

$$\text{Fuel}_{sp} = \frac{E_{PM}}{\eta_{PP} \eta_G} + \frac{HL}{\eta_b} \quad (9)$$

$$\text{Fuel}_{CCHP} = f(E_{PM}) + \text{Fuel}_{\text{aux}, b}$$

$$\text{Fuel}_{\text{aux}, b} = \frac{HL - Q_{rec}}{\eta_b} \quad (10)$$

c. Power only mode:

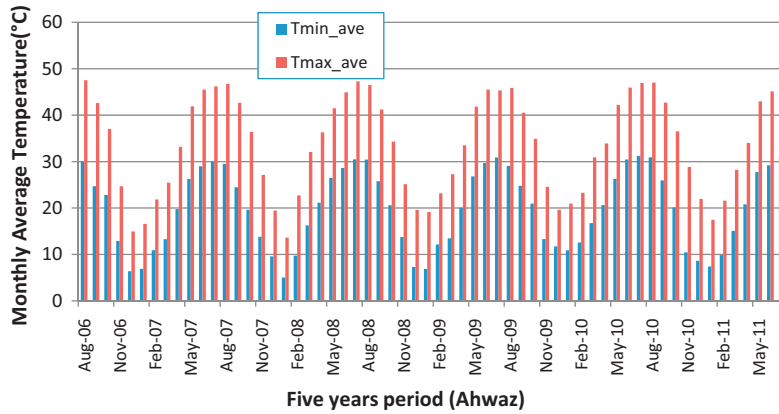


Fig. 2. Monthly average of TDB for Ahwaz during 5 years.

In this mode, no heating or cooling is required, and the only output of the CCHP is the power, hence:

$$\begin{aligned} \text{if } CL = HL = 0 : \\ \text{Fuel}_{sp} &= \frac{E_{PM}}{\eta_{PP}\eta_G} \\ \text{Fuel}_{CCHP} &= f(E_{PM}) \end{aligned} \quad (11)$$

The recovered heat from the engine and fuel consumption of the engine in terms of E_{PM} for a specific system is given as below [13]:

$$\begin{aligned} f(E_{PM}) &= 2.65E_{PM} + 21.44 \\ Q_{rec} &= 1.73E_{PM} + 14.57 \end{aligned} \quad (12)$$

The yearly average of FESR is determined as the summation of the mean FESR for each working subsystem (cooling, heating and power) alone multiplied by its corresponding working time (%) during a year.

$$\begin{aligned} \text{FESR}_{CCHP}^{mean} &= t_{cooling} \cdot \text{FESR}_{cooling,alone}^{mean} + t_{heating} \cdot \text{FESR}_{heating,alone}^{mean} \\ &+ t_{power} \cdot \text{FESR}_{power,alone}^{mean} \end{aligned} \quad (13)$$

In which t is the working time of subsystem during a year. It is obvious that $t_{power} = 1$ because the prime mover is working during the whole year.

4.4. Subsystems of the CCHP system for different climates

Different climates have different cooling and heating hourly load profiles. To decide about the main components of the CCHP system

in different climates it is necessary to find out the answer of the following questions:

- (1) How long the cooling and heating systems are working during the whole year?
- (2) How much is the building peak load of heating and cooling during a year?
- (3) How much of the FESR achieved in the CCHP belongs to the cooling, heating and power alone?

4.5. Sensitivity analysis

In order to investigate the impact of small changes in the four designing parameters of maximum and minimum TDB and TWB on the hourly load profile, the heating and cooling loads of the building are calculated for ± 5 percentage changes in the designing parameters. Therefore, if T is a designing parameter the loads are calculated for $T \pm 0.05|T|$.

5. Results

The hypothetical building with the specified details in the previous sections is considered in five different climates of Iran. It is supposed to provide the cooling, heating and power requirements of this building by utilizing a CCHP system. The idea beyond this study is to see the impact of climate changes on the CCHP size, its components and the FESR achieved by this system.

The research starts with the weather information of the five climates. The cities of Ahwaz, Tehran, Bandar Anzali, Chabahar and Kamyaran are chosen as the candidates for five climates of TSHT, TDC, THC, THT and TDEC respectively. The daily minimum and maximum of TDB and RH for the last five years gathered from the

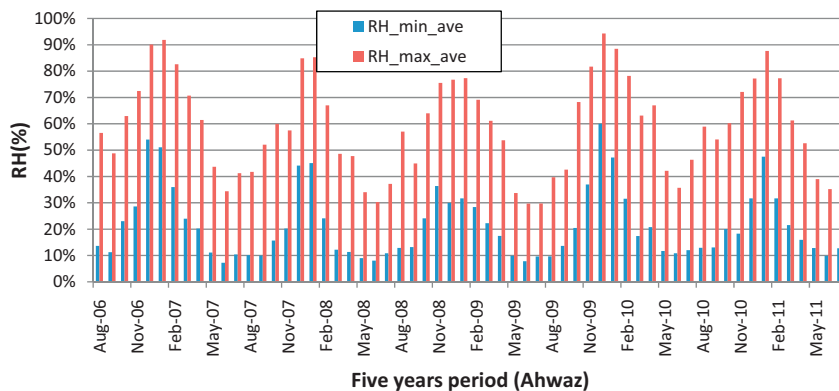


Fig. 3. Monthly average of RH for Ahwaz during 5 years.

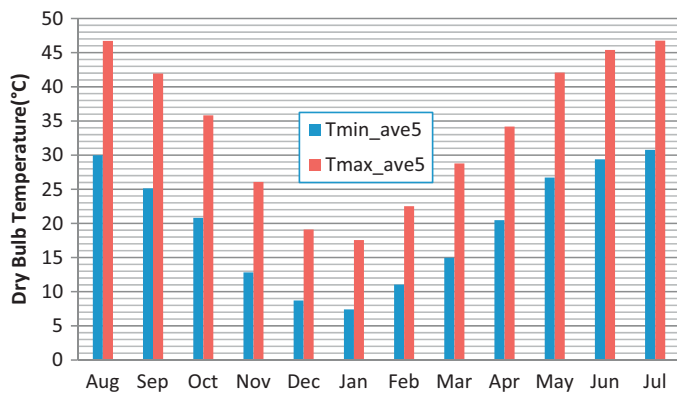


Fig. 4. Five-year average of TDB for Ahwaz.

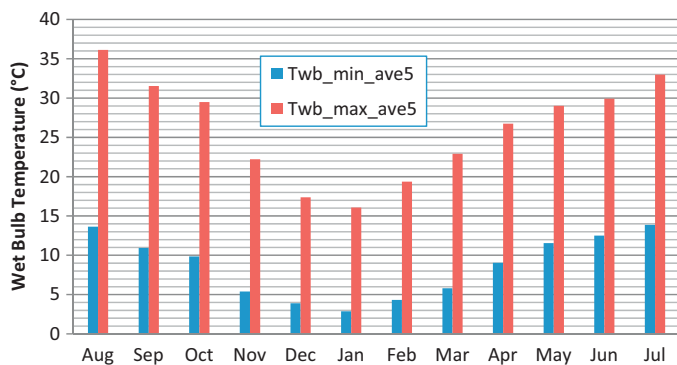


Fig. 5. Five-year average of TWB for Ahwaz.

available archive of Iran Metrological Organization. The monthly averages of TDB and RH during 5 years for the five cities are calculated and as an example, the data for Ahwaz are presented in Figs. 2 and 3. The five-year average of the data calculated for each month and the TWB calculated according to the TDB, RH and the atmospheric pressure are presented in Figs. 4 and 5.

After completion of the weather information the cooling and heating load of the building during the whole year are calculated. The peaks of cooling and heating loads during a year are presented in Fig. 6. According to this figure, the heating peak load for Ahwaz is very small and for Chababhar is zero. As a result, these cities do not need very comprehensive heating systems; a very simple system like a small gas fired furnace can be used to avoid extra expanses and space occupancy of the heating terminals inside the building.

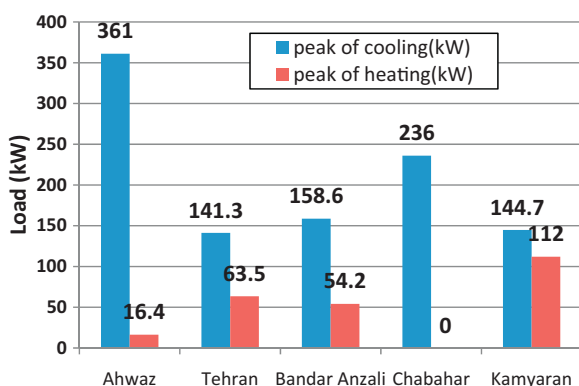


Fig. 6. Peak of cooling and heating loads of the building during a year.

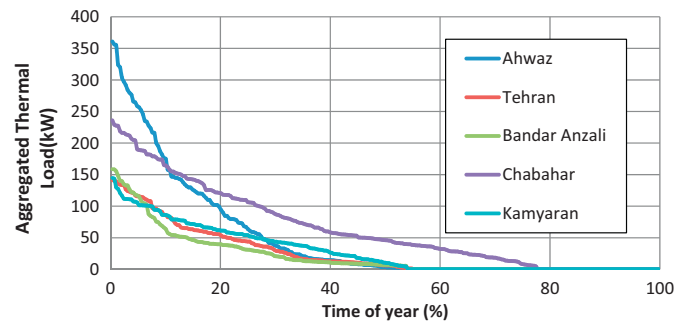
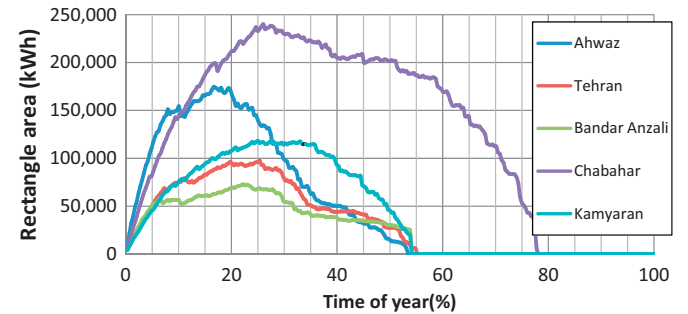


Fig. 7. Aggregated thermal load curves of five cities during year.

Fig. 8. The A_{MRM} of five cities during the whole year.

In the third step, the hourly aggregated thermal load curve of the building is presented in Fig. 7 and the A_{MRM} for the five cities during the year are calculated and presented in Fig. 8. The $A_{MRM,max}$ determined from Fig. 8 is used to determine the size of prime mover, E_{PM} and its full load operation time during a year (Fig. 9). Due to the symmetry in the hourly aggregated thermal load of Kamyaran, the MRM recommends two different but close prime mover sizes of 54 kW and 48.6 kW for this city, in which the size of 54 kW is selected due to having higher yearly mean FESR. The yearly mean FESR of the size 48.6 kW is 30.02%. In this study, the full load operation time recommended by the MRM is not applied to the CCHP system and it is considered that the prime mover works at full load during the whole year. The reason to make this decision is the low efficient power generation and distribution systems in Iran. The overall efficiency of the power plant and the electricity grid is about 25%, while the on-site production of electricity by a reciprocating internal combustion engine gives an electrical efficiency of about 40%. It means that the CCHP system is always saving energy and the minimum increase in the overall efficiency would be about 15% and it can increase to more than 60% as the cooling or heating loads of the building increase, which means an overall efficiency of more than 85% is reachable. In addition, the full load operation

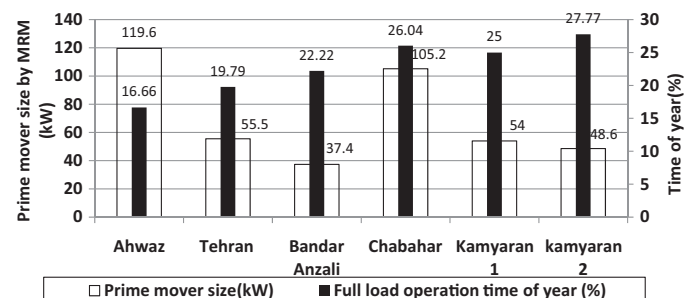


Fig. 9. Recommended size and full load operation time during a year (%) in five representative cities.

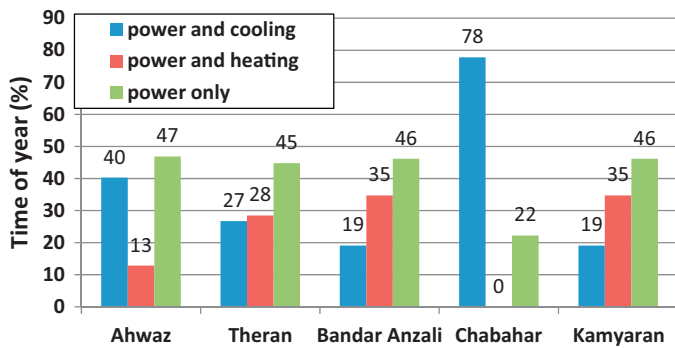


Fig. 10. Time of year (%) when the CCHP work in three working modes.

of the prime mover during the whole year is profitable in the economical point of view; because the government appreciates the extra electricity produced by the CCHP system and purchases it from the producer with higher price with respect to the electricity distributed by the electricity grid. Therefore, the full load operation of the CCHP system during the whole year is profitable technically and economically.

The prime mover size for Ahwaz due to having the highest peak load is the largest (119.6 kW). This large size is due to having very large cooling load and very low heating load. This is the case also for Chabahar, which its cooling peak load is the highest after Ahwaz, its heating load is zero, and the prime mover size is 105.4 kW, close to E_{PM} of Ahwaz. However, for the other climates due to having smaller cooling peak load and smaller difference between the cooling and heating peak loads, the prime mover size gets smaller to about 50 kW or even smaller (Fig. 9).

Three working modes are considered for the CCHP system, the time of year (%) in which the CCHP is working in each working mode is depicted in Fig. 10. This figure confirms that the city of Chabahar does not need heating system but its cooling system works about 80% time of year. The heating system of Ahwaz works about 13% time of year, which according to the low heating peak load, this heating can be provided by an small size and low cost gas fired furnace to avoid piping and occupying room for the heating terminals. For other cities the working time of both heating and cooling systems are considerable, therefore they need to have both cooling and heating systems integrated in the CCHP system.

Fig. 11 shows the variation of the FESR and the overall efficiency ($\eta_{overall}$) of the CCHP system in the city of Kamyaran during the working times of the three working modes. For shortening, the plots of other cities are not presented but their average values are

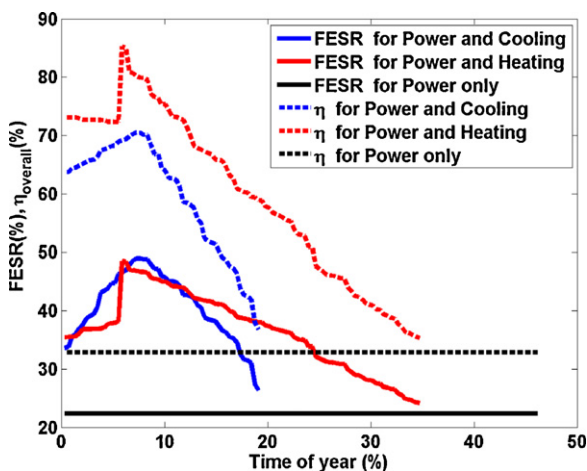


Fig. 11. FESR and $\eta_{overall}$ for Kamyaran in three modes of working during a year.

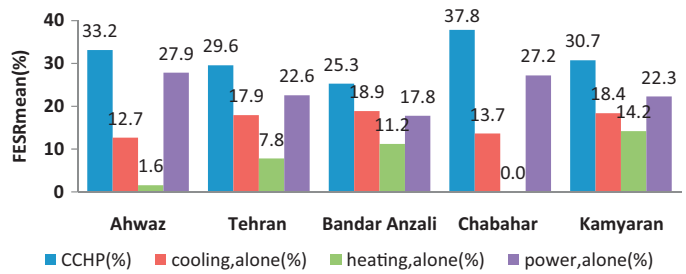


Fig. 12. Annual average FESR for five representative cities.

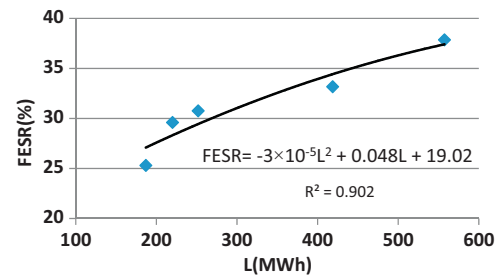


Fig. 13. FESR with respect to the cumulated heating and cooling of climates during a year.

reported in Fig. 12. As the figure shows, saving energy is permanent and the maximum of FESR and $\eta_{overall}$ occurs as the cooling or heating load of the building, approaches the recoverable heat from the engine. As the cooling or heating load of the building, get larger or smaller than the recoverable heat from the engine, both of FESR and $\eta_{overall}$ decreases. Existence of a peak in the yearly FESR in the cooling or heating modes, as what appeared in Fig. 11 means that the system needs an auxiliary boiler to provide the lack of heating load or support the absorption chiller. The results show that in all the climates an auxiliary boiler is necessary.

The annual average of FESR of the CCHP system and its subsystems including cooling, heating and power alone are presented in Fig. 12. The annual averages of FESR of the CCHP system for the climates of THT, TSHT, TDEC, TDC, and THC are 37.85%, 33.16%, 30.75%, 29.60% and 25.30% respectively. This figure also reveals the importance of each subsystem for each climate according to the FESR of that subsystem. According to this figure saving fuel in the heating systems of Ahwaz and Chabahar are not considerable. In addition, it can be concluded that in all the climates $FESR_{power, alone}^{mean} > FESR_{cooling, alone}^{mean} > FESR_{heating, alone}^{mean}$.

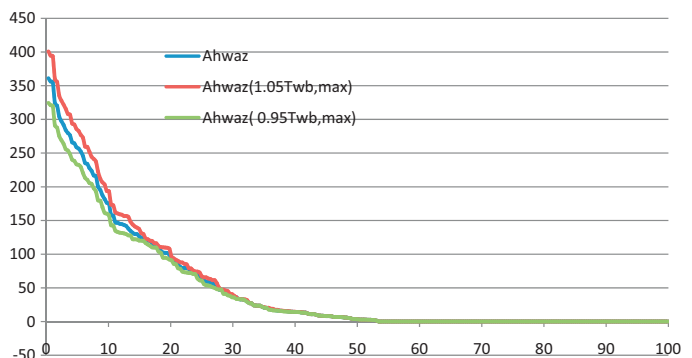


Fig. 14. Impact of $\pm 5\%$ changing the TWB_{max} on the hourly load of Ahwaz.

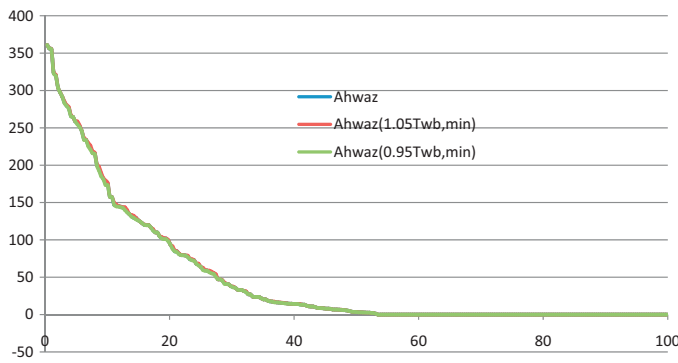


Fig. 15. Impact of $\pm 5\%$ changing the TWB_{min} on the hourly load of Ahwaz.

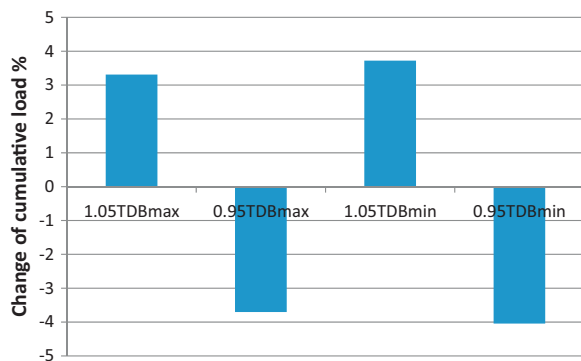


Fig. 16. Impact of $\pm 5\%$ changing the TDB on the cumulative load of Ahwaz.

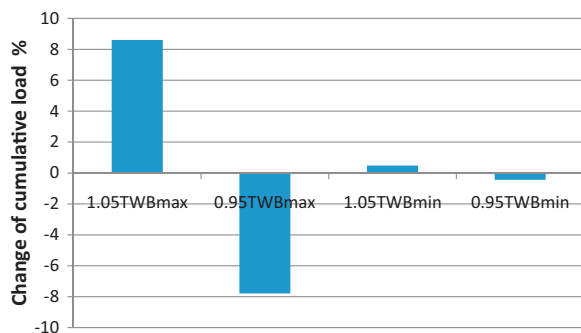


Fig. 17. Impact of $\pm 5\%$ changing the TWB on the cumulative load of Ahwaz.

The mean FESR versus the cumulative heating and cooling loads of the climates (L (MWh)) is depicted in Fig. 13. The curve fitting suggests the following equation.

$$FESR = -3 \times 10^{-5} L^2 + 0.048L + 19.02 \quad (14)$$

$$25.302 \leq L(\text{MWh}) \leq 37.8474$$

This equation is valid in the specified range for L to estimate the FESR of the CCHP system in an arbitrary climate. As the curve shows, by increasing L the FESR increases as well.

The sensitivity analysis shows that by changing the TDB_{max} , TDB_{min} , and TWB_{max} the hourly load profile changes significantly while it is least sensitive to the TWB_{min} (Figs. 14 and 15 as representative are presented for Ahwaz). The results show that by 5% increasing or decreasing the TDB_{min} , TDB_{max} and TWB_{max} the cumulative heating and cooling load of the building increases and decreases with the same order respectively (Figs. 16 and 17). The cumulative load is more sensitive to the TWB_{max} and least sensitive to the TWB_{min} .

6. Conclusions

The present paper, concerns about the impact of climate changes on the design and size of the CCHP system and its subsystems. The analyses show that the sizing and designing of the CCHP system in the THT and TSHT climates has significant differences with other climates. Firstly, the prime mover size is about two to three times larger than the prime mover size in the TDC, TDEC and THC climates. Secondly, the heating system in the TDC, TDEC and THC is compulsory and it is recommended to be integrated with the CCHP system to make use of the waste heat. However, in the THT and TSHT, the heating system is not mandatory and if required a very simple natural gas fueled furnace can be used. This helps to decrease the investment cost and avoid occupying room by the heating terminals. The analysis shows that the CCHP system in the five climates needs an auxiliary boiler to compensate the lack of heating or support the absorption chiller. The FESR of 37.85%, 33.16%, 30.75%, 29.60% and 25.30% achieved for THT, TSHT, TDEC, TDC, and THC respectively. The FESR reaches its maximum when the cooling or heating load of the building approaches the recoverable heat from the engine. The analyses show that an overall efficiency of more than 85% is reachable. In addition, it is concluded that when the cumulative heating and cooling load in different climates increases the FESR also increases and an equation is suggested to examine this dependency. In addition, the sensitivity analysis shows that the cumulative load is more sensitive to the TDB_{max} , TDB_{min} , and TWB_{max} and least sensitive to the TWB_{min} .

The authors recommend the following analyses for the CCHP system that sized and designed in this study to optimize it technically and economically. (1) An economical analysis is necessary to see the impact of climate changes on the investment cost, net present value, internal rate of return and payback period of the CCHP system. This clears if the CCHP system is economical in all the climates or not. (2) An optimization is necessary to investigate different strategies of providing heating, cooling and power of building in different climates.

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